

# **Coupled Ocean Acoustics and Physical Oceanography Observations in the South China Sea: The NPS Acoustic Component**

Ching-Sang Chiu  
Department of Oceanography  
Naval Postgraduate School  
Monterey, CA 93943-5001

Phone: (831) 656-3239      fax: (831) 656-7970      email: [chiu@nps.navy.mil](mailto:chiu@nps.navy.mil)

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## **LONG-TERM GOAL**

My long-term research objectives are: (1) The characterization of meso to internal-wave-scale oceanographic processes that influence broadband sound transmissions in a coastal environment. Central to the characterization are the formulation of accurate forward relations and the quantification of the sensitivities and variability of the various observable acoustic quantities in relation to environmental differences and changes. (2) The development and improvement of high-resolution tomographic inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions. (3) The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

## **OBJECTIVES**

This effort is part of a large, international program called the Asian Sea International Acoustic Experiment (ASIAEX). In collaboration and coordination with other U.S. and Asia investigators participating in ASIAEX, we are carrying out comprehensive measurements and analysis of the different oceanographic factors affecting low frequency ( $< 600$  Hz) acoustic propagation in a shelfbreak region in the Northeastern South China Sea (SCS). Specifically, the NPS acoustic research objectives are:

1. To understand the physics, variability and predictability of low-frequency sound pulse propagation along and across the NE SCS shelfbreak, including the dependence on frequency, source depth and path orientation, and the relations to water-column, bathymetric and sub-bottom structures. Acoustic variables to be considered include the amplitudes, phases, and arrival times of coupled modes (and rays if the ray picture is applicable). Empirical and theoretical relations to the environmental changes will be derived and compared to investigate predictability and establish statistical variances.
2. To expand the acoustic knowledge acquired from previous shelf-slope experiments including shelfbreak PRIMER and SWARM, with added emphases on the horizontal properties of the sound field. Due to source and receiver limitations, both Shelfbreak PRIMER and SWARM were limited to the study of the vertical properties of sound propagation at two narrow frequency bands, 210-235 Hz and 350-450 Hz. The combined ASIAEX assets permit extended investigation into the horizontal properties as well as acoustic transmissions covering the entire low-frequency band from 50 to 600 Hz.

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3. To investigate the advantages and disadvantages of conducting shallow-water tomography using higher-frequency ( $> 400$  Hz) transmissions. The notion is that a higher-frequency transmitter would excite more modes turning at different depths in the water column. Whether resolution enhancement can be realized or not depends on the stratification (i.e., the sound speed profile) of the experimental region and resolvability of the modes. The latter is limited by the signal-to-noise ratio, processing method and receiver array geometry.
4. To formulate and test a phase or time-based modal tomography inverse method for joint estimations of the water-column and sediment properties. This will be a perturbative scheme relying on the fact that low modes are more sensitive to water column variability, whereas high modes are sensitive to sediment parameter uncertainty.

## **APPROACH**

The main experiment was carried out in May of 2001. The approach was to make simultaneous, high-resolution, very high-quality observations of both the acoustic propagation and physical oceanography in the experimental site. Both moored and shipboard oceanographic observations were made, with sufficient spatial and temporal resolution to observe physical phenomena on horizontal scales of a few kilometers and time scales from subtidal to high frequency internal waves (with periods of a few minutes). Simultaneously, acoustic transmissions, aiming at achieving sufficient frequency diversity and spatial coverage, were performed parallel to and across the shelfbreak using both moored and towed sources.

The measurement and analysis are focusing on the horizontal and vertical properties of the shallow-water sound field, their dependence on source depth and frequency, their relations to the water-column, bottom and sub-bottom structure, and the feasibility of a joint sediment-water-column inversion using tomographic techniques. Particularly, the acoustic measurements are to be related to the oceanographic measurements through time-series analyses and modeling studies to gain insights into the detailed physics and variability of the acoustic propagation.

In addition to sampling the oceanographic and acoustic fields in the water column, complimentary measurements of the geoacoustic parameters of the region are also required to allow for a clear separation of the volume interaction effects from scattering due to bottom inhomogeneities. Critical geoacoustic parameters include bathymetry, sediment density, sediment compressional wave speed and sediment attenuation coefficient. Echo sounding, coring and chirp sonar data for inferring these geoacoustic parameters were collected by the geoacousticians participating in ASIAEX prior to and during the main experiment.

## **WORK COMPLETED**

Work completed in FY02 includes:

1. Completed pulse-compression processing of all phase-encoded acoustic signals measured by the WHOI/NPS L-shaped hydrophone array in two separate days, May 8 with the passage of several huge solitons that depressed the shallow isotherms to the sea bottom, and May 4 with a much less energetic soliton field. The L-shaped hydrophone array was moored on the continental shelf that monitored a variety of signals transmitted parallel to and across the shelfbreak by fixed and towed sources.

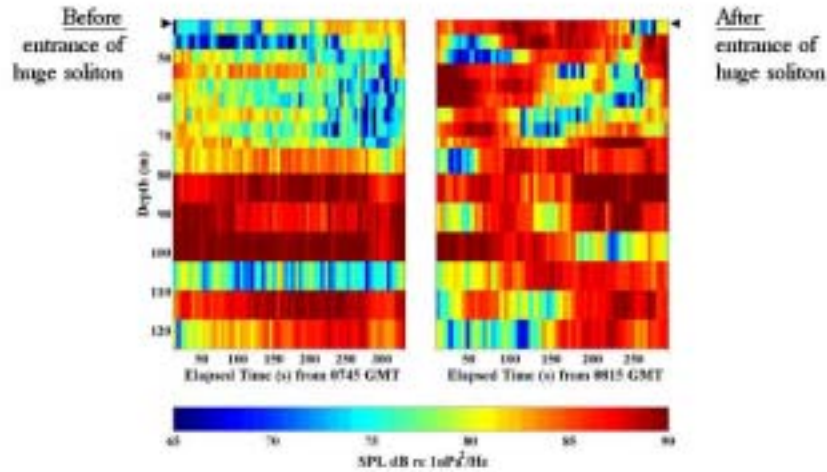
2. Developed an empirical ocean model (with three tuning parameters: soliton phase speed, decay rate and stretch rate) based on moored temperature data to provide space-time continuous sound-speed fields to facilitate both acoustic data analysis and modeling.
3. Analyzed, contrasted and modeled the amplitude fluctuations in the processed signals measured by the vertical segment of the L-shaped array for May 4 and May 8.
4. Served as the ASIAEX Associate International Coordinator to assist in the coordination of international workshops and the Main Point of Contact for dispersing the ASIAEX SCS acoustic data to the foreign ASIAEX investigators.

## RESULTS

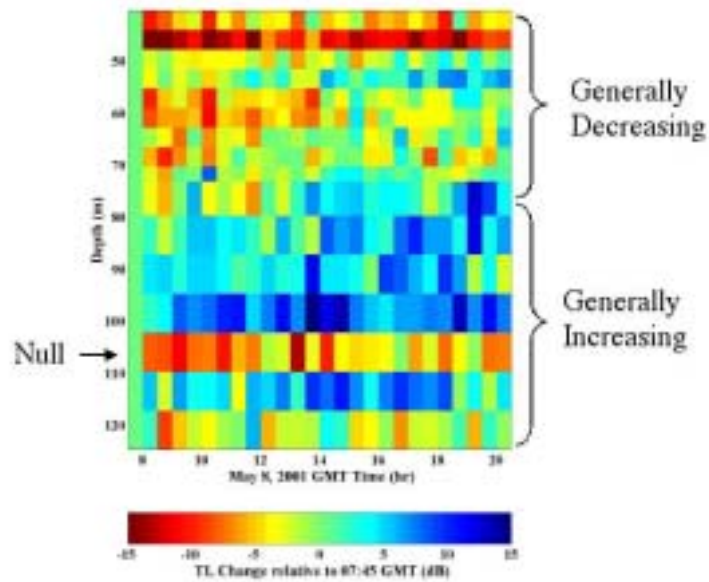
Significant data-analysis and modeling results for May 8 are highlighted here:

Figure 1 shows two snapshots of the processed instantaneous sound pressure level across the vertical aperture of the L-shaped hydrophone array. These signals were transmitted up-slope from a 400-Hz sound source. The leading internal soliton entered the acoustic path at 07:49 producing dramatic changes in the vertical distribution of acoustic energy. Right before the entrance, the high intensity zone was confined below 70 m with a quasi acoustic null just below 100 m. After the entrance, the acoustic intensity was diffused/scattered into the shallower depths. To emphasize that this vertical redistribution/diffusion acoustic phenomenon is long lasting, Fig 2 shows changes in the TL observed by the vertical segment of the L-shaped array over a 12-hr period at 30-min intervals. The changes shown were derived using a 3-minute integration time on the squared pressure, and are relative to the level obtained at 07:45 (a time right before the lead soliton entered the acoustic path). These data clearly show that the TL generally decreased in the upper water-column but increased in the lower water-column as the internal solitons entered and moved along the acoustic path. (Note that the depth between 100 and 110 m in the lower water-column presents an exception where a decrease in TL was consistently realized. This exception was caused by the presence of an acoustic null at that depth before the entrance of the solitons.)

Figure 3 shows snapshots of modeled sound speed (left column), transmission loss (middle column) and relative modal magnitudes (right column). The top row contains the modeled fields 7 minutes before the internal solitons entering an up-slope acoustic path defined by a sound source moored at the 350 m isobath and the receiver array moored on the shelf. The model results show: Before the entrance of the solitons, the acoustic field on the shelf is dominated by two of the lowest modes (1 and 3) which focus the acoustic energy to depths below 70 m. They also combine to form a quasi acoustic null near 100 m. After the entrance of the solitons, the structure of the acoustic field becomes more vertically diffused at ranges beyond the leading soliton. In particular, the acoustic energy on the shelf is no longer primarily trapped in the lower layer but is diffused into the shallower depths through the coupling of low-mode as well as high-mode energy into the intermediate modes (5 through 20). These model results are consistent with the measured data. This important modeling analysis suggests that the vertical transfer or diffusion of sound energy can be well explained by coupled-mode physics: The low-mode/angle and high-mode energy are coupled/scattered into the intermediate modes. The coupling/scattering is mode-number/angle selective, and the selection is controlled by the width of soliton and the mode interference wavelengths at the soliton location.



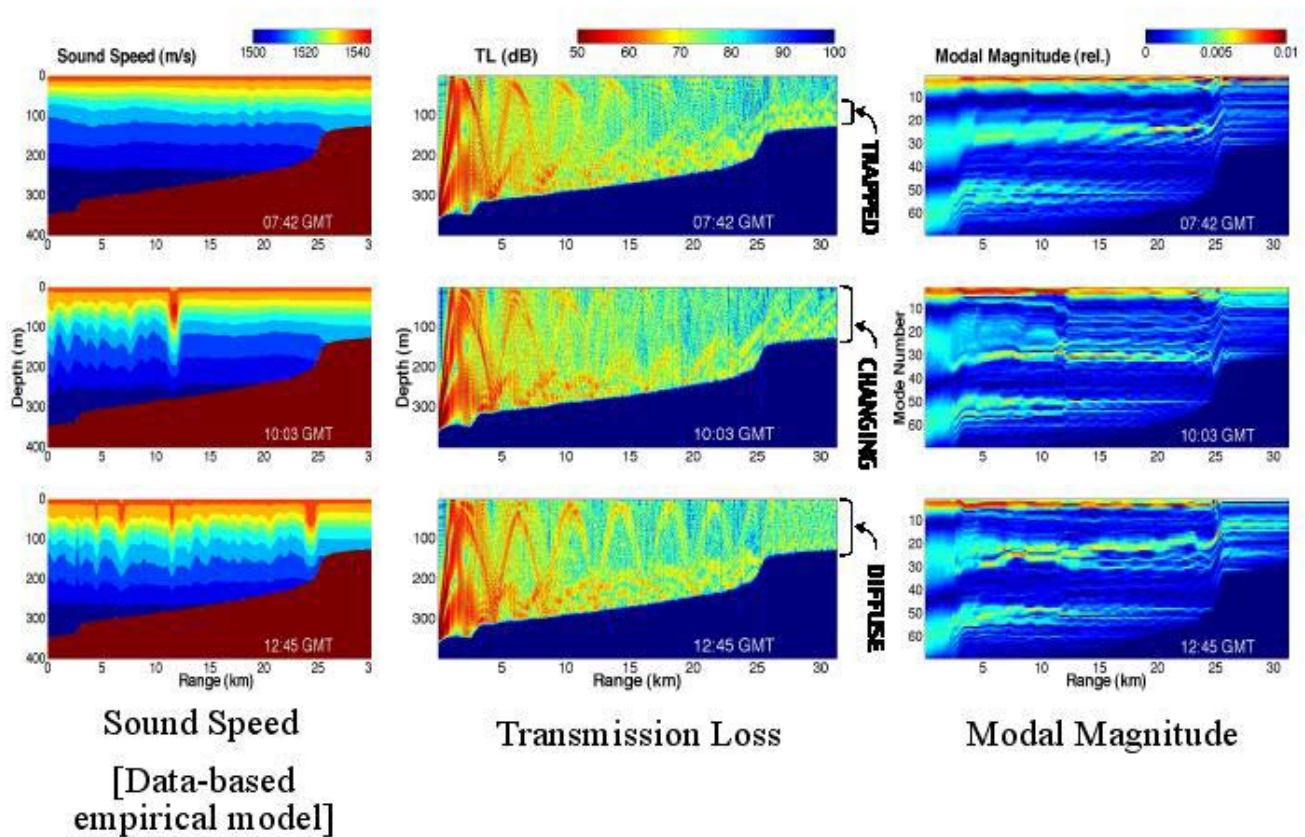
**Figure 1.** Instantaneous sound pressure level at 400 Hz across the vertical aperture of the ASIAEX L-shaped hydrophone array observed at two different times on May 8.



**Figure 2.** Change in 400-Hz TL observed by the vertical segment of the ASIAEX L-shaped array over a 12-hr period at 30-min intervals on May 8.

## IMPACT/APPLICATIONS

The oceanographic and acoustic data gathered in this field study should be valuable in helping to create models of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic.



*Figure 3. May 8 400-Hz Acoustic Modeling Snapshots.*

## TRANSITIONS

This basic research project is integrated with NRL's and Harvard University's applied research efforts in ocean data assimilation/nowcasting and acoustic prediction.

## RELATED PROJECT

This fully integrated acoustics and oceanography experiment should significantly extend the findings and data from SWARM and Shelfbreak PRIMER, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

## PUBLICATION

Chiu, C.-S., S. R. Ramp and J. F. Lynch, "The ASIAEX 2000 Preliminary Experiment in the East China Sea (ECS)," in *Theoretical and Computational Acoustics 2001* (E.C Shang, Q. Li and T.F. Gao editors), World Scientific, 2002.